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(71) Applicant and
(72) Inventor: EFRATY, Avi [IL/IL]; 4 Mevo Hashaked St., POB 132, 90836 Har Adar (IL).

(74) Agent: CALDERON, Hana; Jacob & Hana Calderon, Advocates, Crystal Bldg., 12 Hilazon St., 52522 Ramat Gan (IL).

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(54) Title: VARIABLE PRESSURE CLOSED CIRCUIT DESALINATION

(57) Abstract: A method for sequential closed circuit desalination of a salt water solution by reverse osmosis and an apparatus with at least one circuit that comprises: a container means; one or more desalination modules; lines for conducting the solution from the container to the desalination modules and for recycling desalinated solution from the modules to the container; a circulation means for driving the recycling of the solutions; a pressurizing means for creating sufficient counter pressure to enable reverse osmosis desalination and replacement of released permeate by fresh salt water feed; means for effluent discharge and salt water recharge; means for monitoring the progress of desalination and control means that enable the desalination process to be performed in sequences with either variable pressure or constant pressure applied such that the ratio of applied pressure to osmotic pressure at each stage during the process is maintained above a minimum predetermined value.

VARIABLE PRESSURE CLOSED CIRCUIT DESALINATION

BACKGROUND OF THE INVENTION

The present invention relates to a method and apparatus for the desalination of sea water or brackish water by reverse osmosis.

Desalination by reverse osmosis (RO) occurs when sea water is compressed against semi-permeable membranes such that the pressure applied (henceforth: counter pressure or applied pressure) exceeds the sea water osmotic pressure. Sea water concentration is normally found around 3.5% and this initial concentration is expected to double up during a desalination process of 50% recovery. Accordingly, the behavior of sea water solutions in the concentration range 3.5-7.0 % and the approximate corresponding range of osmotic pressures of 25-48 Bar of such solutions are of immediate interest in the context of sea water desalination by reverse osmosis (RO). In general, induced counter pressure of 35-60% above the osmotic pressure at each concentration level allows for an efficient desalination by RO, this data implying an effective counter pressure in the approximate range of 32-70 Bar for such processes depending on recovery.

The most common RO technology involves the passing of pressurized sea water at approximately 70 Bar through modules comprising semi-permeable membrane elements wherein half the volume is desalted with 50% recovery and the other half is emitted under pressure as process effluent with double the initial salt concentration (7%). This so-called "continuous flow desalination" (henceforth CFD) of 50% recovery involves obtainment of one meter-cube desalted water (permeate) per two meter-cube of dynamically pressurized sea water at 70 Bar, implying a theoretical specific energy of about 4 Kwh/m^3, or about 5 Kwh/m^3 assuming 80% efficiency.

Application of a turbine for energy recovery from the pressurized effluent of the CFD process is expected to yield a specific energy of 3.3- 3.9 Kwh/m^3 for turbine efficiency in the range of 80-50%. Practical specific energy consumption of an advanced CFD apparatus with energy recovery means is presently found in the range of 3.75-4.25 Kwh/m^3.

The CFD technology involves triple investment in power components, since two meter-cube sea water are pressurized dynamically in order to obtain one meter-cube of desalted water, and the energy of one meter-cube effluent needs to be recovered by means of a turbine. About 25% of the production costs of desalted sea water by the CFD method represents financial expenses due to the heavy investment in power components.

The widespread CFD method utilizes desalinization cells in the form of commercial modules comprised of semi-permeable membrane elements in contact with pressurized sea water with permeate released on the inside of the membrane elements. Common commercial modules for sea water desalination with 99.0-99.6% salt rejection consist of shell-covered cylindrical containers of typical dimensions (e.g., 100x20 cm) and weight: (e.g., 16 Kg) with semi-permeable membrane elements of daily permeate output in the range of 17-24 m^3/day (11.8 -16.66 liter/min). The efficient application of commercial modules requires a specified minimum flow ratio of concentrate to permeate (e.g. 1:5) and a specified maximum allowed feed flow through modules (e.g. 300 liter/min). Maximum pressure loss in commercial modules is generally of the order of 15 psi (2/3 Bar).

In order to effect continuous flow desalination of sea water (3.5%) with 50% recovery by the CFD method, about five typical modules need to be connected "head-to-tail" so as to enable the step-wise build-up of the desired recovery. The typical minimum flow ratio of concentrate to permeate of 5:1 at the outlet of five joined modules for 50% sea water recovery also implies flow rate ratios of

9:1, 8:1, 7:1, 6:1 and 5:1 at the outlet of the 1st, 2nd, 3rd, 4th and 5th joined modules, respectively. The flow rate ratio of inlet feed(1st module) to effluent outlet(5th module) of 2:1 in this instance manifests 50% recovery, or flow rate ratio of 1:1 of effluent to permeate through the continuous process. The concentration and osmotic pressure of effluent in the CFD method constitute limiting factors with process fixed operational pressure maintained some 35% above said osmotic pressure of effluent.

The application of CFD to brackish water is done by complete analogy to sea water and also involves "head-to-tail" joined modules with the number of units determined by desired recovery and fixed constant pressure of operation maintained at some 35% above the osmotic pressure of effluent. The recovery percentage as function of the number (n) of joined modules is expressed by [n/(n+**r**)]x100 ; wherein **r** stands for the minimum flow rate ratio of concentrate to permeate at the outlet. If the minimum required flow rate ratio of concentrate to permeate at the terminal module is expressed by **r**=5, the recovery rates of 19.7, 28.5, 37.5, 44.4, 50.0, 54.5, 58.3, 61.5, 64.2, 66.6, 68.7 and 70.6% correspond to the number (n) of joint modules being 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 units, respectively. Pressure loss encountered due to the joining "head-to-tail" of too many modules, mainly characteristic of high recovery brackish water processes, is rectified by means of pressurizing booster pump(s).

The need for extensive application of power components is an inherent disadvantage of the CFD technology that may only be eliminated by the conception of new technologies.

A desalination system with reduced power requirements has been claimed in recent patents WO 97/29049 and WO 00/00274 by Avero et al. These patents, entitled "Sea Water Reverse Osmosis Desalination System, with Permanent

Renewal of the Water to be De-Salted" and "Water Desalting Installation through Reverse osmosis with Pressurized supply tanks in Continuous Kinetic Cycle" describe variations of the same system. The system claimed by Avero et al. consists of a low pressure auxiliary pump, a high pressure pump in parallel to a circulation pump which feeds into an osmosis chamber, one or more pairs of closed-circuit supply chambers of alternating low and high pressure functions, and intricate plumbing, valves and pistons arrangements. Supply chambers according to Avero et al. are of a preferred toroidal shape with oval, zigzag, helical or other shapes also possible provided that water flow continuously in the same direction inside the chamber.

Statements by Avero et al concerning performance of the system include low power requirements, low energy costs, reduced plant and maintenance costs, extended working life of installation, and improved economic viability. Further stipulations are made concerning the use of wind or sunlight as power sources of such desalination system. These statements have not been substantiated by experiments and/or by computer simulations of concrete examples, and thus should be viewed with caution. Flow through the two, or more, closed circuits of advised shapes with complex designs of pistons, valves and intricate plumbing is expected to induce extensive pressure losses due to friction in the system claimed by Avero et al. Most components in the system claimed by Avero et al have complex designs different from standard commercial items, a disadvantage that is expected to reflect in increased cost of system. In the claimed system little attention is given to the actual desalination step, said to take place in an "osmosis chamber" of unspecified characteristics, thus, making it impossible to assess the performance of the most critical element of any desalination system. Little attention, if any, is given in the description of the system claimed by Avero et. Al. to pertinent information concerning pressure conditions during operation and efficiency of components making it difficult to assess the energy requirements and commercial feasibility of the claimed method.

In order to effect a sharp drop in the cost of desalination, considerably cheaper apparatus should be made available with energy consumption reduced substantially. Lowering costs of apparatus of reduced energy consumption requires the conception of an entirely new technology of lower power demand compared to the CFD method.

The objectives set-forth for the development of an effective and simple new desalination technology which saves power and energy could not be met in the context of the complex technology suggested by Avero et al. These objectives have been met in full by means of an inexpensive desalination apparatus of simple design made to operate on the basis of a closed circuit, and comprised of commercial components of proven performance and known durability, subject of the present invention.

SUMMARY OF THE INVENTION

The present invention proposes an apparatus and methods for desalination of sea water, or brackish water, on the basis of reverse osmosis using a closed circuit, wherein feed is recycled from a container through parallel desalination modules by a circulation driving means and counter pressure is created by a pressurizing means which also replaces the released permeate by fresh feed supply. The volume of feed pressurized into the closed circuit during the desalination sequence is monitored by means of a flow meter, this volume at any given instance being equal to the volume of released permeate. The circulation driving means is made to operate at low inlet-outlet pressure difference under module specification of flow ratio of concentrate to permeate, and the pressurizing means may be made to deliver variable pressure as function of the recovery during the desalination sequence, as monitored by the

flow meter. Counter pressure of desalination at module outlets is maintained at a fixed ratio above osmotic pressure during the entire desalination sequence.

The variable pressure closed circuit desalination apparatus may be made to operate continuously by adding a second container and alternating between containers such that while one container is actively engaged in desalination the other container is being recharged under atmospheric pressure. The alternating containers design of the inventive apparatus allows the combining of variable pressure desalination sequences into a continuous process, since the modules may be operated non-stop at their specified permeate output.

The inventive method and apparatus of variable pressure closed circuit desalination by reverse osmosis may be implemented by a simple apparatus made of readily available commercial components and it allows low cost desalination at highly significant savings in power and energy.

The inventive apparatus may be operated at constant pressure such that the costs of the pressurizing means are considerably reduced while the energy expenditure is still kept lower than in the methods of the prior art.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig.1 Is a schematic drawing of an apparatus for Non Continuous Closed Circuit Desalination of sea water, or brackish water, with a six module configuration.

Fig.2 Is a schematic drawing of an apparatus for Continuous Closed Circuit Desalination of sea water,. or brackish water. with a six module configuration.

DETAILED DESCRIPTION OF THE INVENTION

The present invention provides a solution to the problem of extensive energy consumption and high costs involved in reverse osmosis desalination processes of the prior art by proposing an apparatus and method for sequential desalination of sea water, or brackish water, by reverse osmosis comprised of a closed circuit, wherein feed is recycled from a container through parallel desalination modules by a circulation pump and counter pressure is created by a pressurizing pump which also replaces the released permeate by fresh feed supply.

In accordance with the inventive method the volume of the feed pressurized into the closed circuit during the desalination sequence is monitored by means of a flow meter, this volume at any given instance being equal to the volume of released permeate. The volume of released permeate being directly proportional to the raise in osmotic pressure, the monitoring of this volume provides the means to control the counter pressure of desalination at modules' outlets such that it is kept at a fixed ratio above osmotic pressure throughout the desalination sequence.

In accordance with the novel apparatus and method, the single element modules are installed and fed in parallel instead of the "head to tail" arrangement of joined elements in modules of the prior art. As a result, the osmotic pressure build up is not the sum total of the osmotic pressure differences accumulated along the "head to tail" sequence of the modules used in the apparatus, but instead, it is limited to the osmotic pressure created in a single module, with all the modules applied in the apparatus operating in parallel.

It is another advantage of the invention that by gradually increasing the counter pressure of desalination such that it is kept at a fixed ratio above the osmotic

pressure of concentrate at modules' outlet, the mean added pressure above osmotic pressure throughout the process is only about half that required by the CFD method of the prior art, and this implies signficant saving in power and energy by the inventive method.

In accordance with another advantage of the invention, the circulation means is made to operate at low inlet-outlet pressure difference in compliance with modules' specifications of flow ratio of concentrate to permeate, thus enabling an increased save in energy and costs in the overall context of the process.

The novel apparatus and method eliminate the need for the application of vast over-power as well as the need for excess power recovery practice characteristic of the existing CFD methods.

In order to demonstrate the energy and/or power saving that may be achieved in an apparatus according to the invention, it may calculated that the gradual application of counter pressure that equals the osmotic pressure plus 35% extra for sea water (3.5%) desalination with 50% recovery implies a mean osmotic pressure of 37 Bar [(25-49)/2], mean counter pressure of 50 Bar - about 35% above mean osmotic pressure [1.35x37], mean theoretical specific energy of 1.41 [50/35.52] Kwh/m^3 and mean practical specific energy of 1.82 [1.41x1.1/0.85] Kwh/m^3 such that the process will only require 10% extra energy above that required for the actual desalination step, with an overall efficiency of 85%. These energy projections imply a greatly reduced power demand by the inventive method compared with the CFD method, and thus, lower investments in power units and maintenance costs.

In accordance with a different embodiment of the inventive apparatus and method, the variable pressure closed circuit desalination apparatus comprises a pair of alternating containers such that while one container is actively engaged in desalination the other container is being recharged under atmospheric

pressure. The alternating containers design of this embodiment allows the combining of variable pressure desalination sequences into a continuous process, since the modules may be operated non-stop as expected of a genuine continuous desalination process.

In accordance with another aspect of the inventive apparatus and method, the variable pressure closed circuit desalination apparatus may be operated under constant pressure such that the costs of the pressurizing means are considerably reduced while the energy expenditure is still kept lower than in the methods of the prior art.

Fig.1 is a schematic drawing of an apparatus that is a preferred embodiment of the inventive apparatus. As seen in Fig. 1, the inventive desalination apparatus comprises a pressurized sea water container CN (henceforth "container") which feeds in parallel a plurality of desalination modules M_1-M_6. It will be understood that the number of modules is not limited to the six modules shown in Fig. 1 and it may be smaller or larger according to different design requirements. It is one of the advantages of the inventive apparatus that it may be operated with the commercial modules known from the prior art. It is also envisaged that different kinds of modules may be designed to be applied in the inventive apparatus, or the apparatus may be provided with commercial modules not known at the time of this invention. The modules to be applied in the inventive apparatus will generally comprise one or more elements within a housing. The outlet of concentrate from the modules is returned to the container CN by means of a circulation pump CP, the said circulation pump CP operated at low inlet-outlet pressure difference. The desired hydrostatic pressure in the container CN and modules M_1-M_6 is created by means of a pressurizing pump PP that feeds sea water into the apparatus through a valve V_P, replacing the volume of released permeate, designated by an arrow A, by fresh sea water supply designated by arrow E. The volume of the sea water supply is being monitored continuously by means of a flow meter FM. The pressurizing pump PP is made to actuate

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either at constant pressure or at progressively increased pressure as function of desalination recovery manifested by monitored volume on the flow meter FM. The apparatus also comprises lines L_1 for conducting supply from the container CN to the modules M_1-M_6 via secondary lines $L_{1.1}$, $L_{1.2}$, $L_{1.3}$, $L_{1.4}$, $L_{1.5}$ and $L_{1.6}$. The apparatus further comprises line L_2 for returning to the container CN the partially desalinated sea water from the modules via secondary collecting lines $L_{2.1}$, $L_{2.2}$, $L_{2.3}$, $L_{2.4}$, $L_{2.5}$, $L_{2.6}$ driven by circulation pump CP. It will be understood that the design of the desalination circuit and lines as shown in Fig.1 is schematic and simplified and is not to be regarded as limiting the invention. In practice the desalination apparatus may comprise many additional lines, branches, valves and other installations or devices as necessary according to specific requirements while still remaining within the scope of the invention and the claims.

Referring again to Fig.1, the desalination apparatus further comprises a line AA for the collection of released permeate (desalted solution) from the modules outlets A_1, A_2, A_3, A_4, A_5 and A_6, an optional line B for feed recharge into the container CN from an upper reservoir, an inlet-outlet line C for filling and emptying the container CN through a discharge–recharge pump DRP, an optional line F for effluent discharge from the container CN by gravity and a series of valves V_1-V_4 for controlling the flow to and from the said container CN. A line D is provided for conducting the fluids between the container CN and the valves V_1-V_4. A further valve V_5 controls the flow from the desalination units M1-M6 to the container CN while valve V_6 controls the flow from the container CN to the desalination units M_1-M_6. A valve AP enables opening the container CN to atmospheric pressure. The valve AP remains closed during operation as indicated by the vertical line crossing the rhomboid that is a schematic representation of the valve AP. The direction of flow in the inventive apparatus is indicated by light grey arrows. Pressurized lines of the desalination circuit are indicated by a continuous line and non-pressurized lines are indicated by dashed or dotted lines. It will be understood that the lines and valves shown in

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Fig.1 are but one way of implementing the invention and many other installations may be envisaged for diverse embodiments of the invention.

The apparatus according to the invention may be realized using a large number of modules such that the modules are arranged in multiple parallel lines, each line supplied in parallel with solution for desalination from the main line of the apparatus and each module within each line also supplied in parallel. In such an apparatus separate circulation means may be used for each of the said lines respectively or a single circulation means may be used for all of the said lines.

The pressurizing means or the circulation means or both may be implemented by two or more pumps installed in parallel or any other design according to specific requirements.

In accordance with the inventive apparatus, the container need not be a vessel of large volume and it may be implemented as a pipe or duct section.

The desalination method of the invention involves the following steps, described hereinbelow with reference to the apparatus of Fig. 1: **(I)** the entire apparatus is filled with fresh sea water or brackish water supply; **(II)** the flow meter FM is set to zero and the pressurizing pump PP is actuated at a desired initial pressure; **(III)** the circulation pump CP is actuated at low inlet-outlet pressure difference such that flow rate of concentrate to permeate is consistent with specifications of modules; **(IV)** the sea water or brackish water is driven from the container via valve V_6 to line L_1 and into the modules where reverse osmosis takes place via secondary lines $L_{1.1}$-$L_{1.6}$, the desalted solution (permeate) is released from the modules at A via a line AA with connections to modules at A_1-A_6 while concentrated solution is collected from the modules via collecting lines $L_{2.1}$-$L_{2.6}$ and driven by circulation pump CP into the container CN via line L_2 and valve V_5 and the concentrated solution is again driven out of the container through valve V_6 ; **(V)** the above described cycle is repeated until the desired

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desalination recovery is attained while the pressure output of the pressurizing pump PP is either maintained constant or raised progressively as function of process recovery monitored by means of the flow meter FM; **(VI)** when the desired desalination recovery has been attained, the container CN is disconnected from the desalination circuit by means of the valves V_5 and V_6, then opened to atmospheric pressure, and its content is replaced with fresh supply of sea water either by gravity from an upper reservoir via line B, or fresh supply of sea water is pumped into the container CN via the valves V_3, V_1 by means of the discharge-recharge pump DRP, the freshly recharged container CN is sealed and pressurized, the flow meter FM is reset to zero, and a new desalination sequence is initiated by reconnecting the container via the valves V_5 and V_6 to the desalination circuit and actuating the circulation pump CP.

It will be obvious to those versed in the art that the desalination method of the invention may be operated in desalination apparatus of different designs as explained above in respect of the inventive apparatus as long as such an apparatus comprises a closed circuit of conducting lines with a container, one or more desalination modules supplied in parallel, a pressurizing means, a circulating means and a flow monitoring means.

The static pressurization of sea water in the container and through the circuit of the apparatus requires a rather low amount of energy due to the extremely low compressibility of water. If this small static pressurization energy is ignored, the power and energy requirements of the apparatus shown in Fig.1 originate primarily from three different sources. <u>First</u>, the energy needed to drive the dynamic flow of fresh sea water supplied at a desired applied pressure (designated $\mathbf{p_{ap}}$) by means of the pressurizing pump PP, or to drive the equivalent permeate flow **(n.Q)** released through **n** modules, each having a flow rate **Q.** <u>Second</u>, the energy required for the circulation flow per **n** modules (that equals **n.Q'** where circulation flow per one module is **Q'**), to be generated by means of the circulation pump CP at low inlet-outlet pressure difference

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(Δp). As the flow rate ratio of concentrate to permeate is defined **$r=Q'/Q$**, the flow rate **Q'** may be expressed by the equation **$Q'=r.Q$.** Third, the energy required for container (**V**, m^3) recharge-discharge under a specified pressure **p.**

The power(P_{PP}) and specific energy (SE_{PP}) demand of the pressurizing pump PP are expressed by equations (1) and (2), respectively, wherein f_{PP} stands for the efficiency factor of the pressurizing pump PP. The power(P_{CP}) and specific energy (SE_{CP}) demand of the circulation pump CP are expressed by equations (3) and (4), respectively, wherein f_{CP} stands for the efficiency-factor of the circulation pump CP. The designation t (minutes) in equation (4) stands for the time elapsed since the start of a particular desalination sequence. The energy demand for container discharge - recharge (E_R) is expressed by equation (5), and the specific energy (SE_R) per meter-cube permeate is expressed by equation (6), wherein f_R stands for the efficiency-factor of the discharge-recharge pump(s), V for the volume of the container, and v for the volume of released permeate. The total specific energy of desalination required by the apparatus in Fig.1, or a similar apparatus according to the inventive apparatus is expressed by equation (7).

(1) $P_{pp}(\text{Kw}) = (n \,.\, Q \,.\, p_{ap}) \,/\, (592\ f_{PP})$

(2) $SE_{pp}(\text{Kwh/m}^3) = [\, p_{ap} \,/\, (592\ f_{PP}) \,]\ [1{,}000/60\,]$

(3) $P_{CP}\,(\text{Kw}) = (n.Q'.\Delta p) \,/\, (592\ f_{CP})$

(4) $SE_{CP}(\text{Kwh/m}^3) = \{ (n.Q'.\Delta p) \,/\, (592\ f_{CP}) \}.[t/60\,]\,[1{,}000/(n.Q.t)]$
$= \{ (r.\Delta p) \,/\, (592\ f_{CP}) \}\,[1{,}000/60\,]$

(5) $E_R = 2\,(V.p\,)/(\,35.53\ f_R\,)$

(6) $SE_R\,(\text{Kwh/m}^3\ \text{permeate}) = 2\,E_R/v = 2\{\,(V.p) \,/\, (\,35.53\ f_R)\,\}\,[1/v\,]$

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(7) $SE_{TOTAL}(Kwh/m^3) = SE_{PP} + SE_{CP} + ES_R$

$= \{p_{ap}/(592\, f_{PP})\}\, [1{,}000/60] + \{(r.\Delta p)/(592 f_{CP})\}[1{,}000/60] + 2\{(V.p)/(35.53.f_R)\}[1/v]$

The preferred embodiment shown in Fig.1 has a non-continuous nature, which implies frequent stopping of the desalination process between consecutive sequences for container discharge and recharge. The apparatus of the schematic design in Fig.2 is a different preferred embodiment that provides an improvement of the former design by utilizing a second container as well as a first container.The dual container configuration in the design of this preferrred embodiment allows continuous utilization of the modules as expected of a genuine continuous process. The application of the dual container configuration is rather simple, since while one container is actively engaged in the desalination circuit, the other, disengaged container is being discharged - recharged and vice versa. Ideally, the duration of a sequence of container-full desalination cycles should last a little longer than the discharge-recharge operation of the disengaged container, this to allow for the pressurization of the disengaged container before it is reconnected to the desalination circuit. Switching from one container to another accompanied by a reset of the flow-meter to zero, will establish new sequences of either constant or variable counter pressure, the latter as function of the desalination progress monitored by the flow meter. The dual container design provides the means for making the modules in the desalination apparatus actuate continuously under static pressure conditions, rather than under the dynamic flow conditions of the type offered by CFD which involves a significantly higher specific energy demand.

As seen in Fig.2, the circuit of the dual container desalination unit is similar to the single container unit of Fig.1, with some differences owing to the inclusion of two sea water containers CN_1 and CN_2 instead of the single container CN of the embodiment of Fig.1. The two containers CN_1 and CN_2 may be operated alternatingly to feed a plurality of desalination modules M_1-M_6, however the

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number of modules is not limited to the six modules shown in Fig.2 and it may be smaller or larger according to different design requirements. As in the embodiment of Fig.1, the unit of Fig.2 may be operated with the commercial modules known from the prior art or different kinds of modules may be designed to be applied in the inventive apparatus or the apparatus may be provided with commercial modules not known at the time of this invention. Referring again to Fig.2, the circuit of the dual container desalination unit further comprises valves AP_1 and AP_2 for opening the containers CN_1 and CN_2, respectively, to atmospheric pressure, lines D_1 and D_2 for inlet of fresh feed to the containers CN_1 and CN_2 or outlet of concentrate from the said containers CN_1 and CN_2 respectively, a line L_2 for collecting the concentrate from the modules M_1-M_6 via collecting lines L_1-L_6, a circulation pump CP for driving the flow of the said concentrate, a pair of valves $V_{5.1}$, $V_{5.2}$ directing the flow of the concentrate from the line L_1 to the container CN_1 or the container CN_2 as required, a pair of valves $V_{6.1}$, $V_{6.2}$ for letting out the pressurized fluid from the container CN_1 or from the container CN_2 as required, a line L_2 for conducting the said fluid from the container in operation to the modules M_1 – M_6 via secondary lines $L_{1.1}$-$L_{1.6}$, and a line A for collecting the desalted solution (permeate) from the modules via secondary lines A_1-A_6 such that the permeate is released at arrow A. Valves V_2 and $V_{1.1}$ enable recharging the container CN_1 from an upper reservoir or the container CN_1 may be recharged by pumping the fresh sea water or brackish water supply into the container CN_1 through the inlet-outlet means C via valves V_3 and $V_{1.1}$ by actuating the discharge-recharge pump DRP. Similarly, the container CN_2 may be recharged from an upper reservoir via valves V_2 and $V_{1.2}$ or fresh supply of sea water or brackish water may be pumped into the container CN_2 by the action of the discharge–recharge pump DRP via valves V_3 and $V_{1.2}$. Valve V_4 enables effluent discharge by gravity from either container CN_1 via valves $V_{1.1}$, V_4 or container CN_2 via valves $V_{1.2}$, $V_{1.4}$. The discharge-recharge pump DRP enables discharge of the container CN_1 via valves $V_{1.1}$, and V_3 or of the container CN_2 via valves $V_{1.2}$, V_3.

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The direction of flow in the inventive apparatus is indicated by light grey arrows. Pressurized lines are indicated by a continuous line and non-pressurized lines are indicated by dashed or dotted lines. It will be understood that the lines and valves shown in Fig.2 are but one way of implementing the invention and many other installations may be envisaged for diverse embodiments of the invention. It will be further understood that the valves and pumps and any other devices may be situated at different locations within the inventive apparatus. Thus the circulation pump CP may be installed along line L_2 instead of line L_1 as shown in Fig.2. It will be further understood that several pressurizing means may be applied in parallel and simultaneously instead of the single pumps depicted in Fig.2. Likewise, it will be understood that more than one circulation pump may be applied in parallel and/or in line to generate the desired closed circuit flow according to modules specifications.

Fig.2 shows an operational phase with container CN_2 actively engaged in the desalination cycle, while at the same time container CN_1 is disengaged and undergoing effluent discharge as part of the discharge-recharge operation. During this phase the valve $V_{6.2}$ is open in the direction of flow, allowing the fluid from the container CN_2 to flow into the line L_1 and reach the modules M_1-M_6 via the secondary lines $L_{1.1}$-$L_{1.6}$. The valve $V_{5.2}$ is also open in the direction of flow, such that the concentrate from the modules M_1-M_6 may reach the container CN_2 via the collecting lines $L_{2.1}$-$L_{2.6}$ and the line L_2, driven by the circulation pump CP. This cycle is repeated several times until the concentrate and its osmotic pressure manifest the desired recovery level of the desalination process. In the phase of operation depicted in Fig.2 the effluent is discharged form container CN_1 by the opening of valves $V_{1.1}$ and V_4 together with the atmospheric pressure valve AP_1. When the discharge operation is completed, container CN_l is filled with fresh sea water or brackish water by opening valves V_2 and $V_{1.1}$ for feed recharge from an upper reservoir, or by opening the inlet-outlet passage C as well as valves V_3 and $V_{1.1}$ and actuating the discharge–recharge pump DRP to drive the fresh water supply into the said container CN_1.

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During this phase the valve AP_1 is open, however when the filling of container CN_1 with fresh sea water feed is completed, valve AP_1 is closed and pressurization of the container takes place by opening of either valve $V_{6.1}$ or $V_{5.1}$, not both, thereby blocking circulation through the container CN_1 and enabling pressurization. Instead of stopping the process when the desired recovery is attained by the active desalination circuit as in the embodiment of Fig.1, the container CN_2 is now relieved by the container CN_1 that has already been filled with fresh feed of sea water, or brackish water, and pressurized. The container CN_2 is disconnected from the desalination circuit by closing the valves $V_{6.2}$ and $V_{5.2}$ and the container CN_l connected simultaneously to the desalination circuit instead of CN_2 by the opening of both valves $V_{6.1}$ and $V_{5.1}$. The relieved container CN_2 is to undergo replacement of concentrate effluent with fresh feed of sea water, or brackish water, followed by container pressurization, by complete analogy to the procedure already described for CN_1. The valve AP_2 is opened to let atmospheric pressure into the container CN_2 and the valves $V_{1.2}$ and V_4 are also opened for effluent disharge by gravity via line F. In accordance with another alternative enabled by the preferred embodiment of Fig.2, the container CN_2 may be discharged and recharged by means of the discharge-recharge pump(s) DRP, via the valves $V_{1.2}$ and V_3 and the inlet-outlet means C. The container CN_1 then relieves the container CN_2 by the valves $V_{5.1}$ and $V_{6.1}$ being opened to allow the flow of concentrate from the modules M_1-M_6 into the container CN_1 and from said container back into said modules, this operation taking place under pressure created by the pressurizing pump PP while the valve AP_1 is closed.

As seen in Fig.2, that shows the container CN_2 in operating state, the outlet of concentrate from the modules M_1-M_6 is returned to the container CN_2 by means of a circulation pump CP operated at low inlet-outlet pressure difference. The desired hydrostatic pressure in the container CN_2 and modules M_1-M_6 is created by means of a pressurizing pump PP that feeds sea water into the apparatus through a valve Vp, replacing the volume of released permeate, designated by

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an arrow A, by fresh sea water supply designated by arrow E. The volume of the sea water supply is being monitored continuously by means of a flow meter FM. The pressurizing pump PP is made to actuate either at constant pressure or at progressively increased pressure as function of desalination recovery manifested by monitored volume on the flow meter FM. It will be understood that the design of the continuous cyclic desalination circuit and lines as shown in Fig.2 is schematic and simplified and is not to be regarded as limiting the invention. In practice the desalination apparatus may comprise many additional lines, branches, valves and other installations or devices as necessary according to specific requirements while still remaining within the scope of the invention and the claims. Thus the circulation pump CP may be installed along line L_2 instead of line L_1 as shown in Fig. 2, two circulation pumps or two pressurizing pumpsn may be installed in parallel, etc.

The general design of an apparatus for continuous desalination according to the invention is comprised of a battery of n modules (M_1, M_2, M_3 ...M_n) or several such batteries connected in parallel, one pressurizing means or several pressurizing means operated simultaneously in parallel, one circulation means or several such circulation means, one circulation means for each of the said batteries respectively, and two containers or more of which in any given point of time one container is engaged in the closed circuit of desalination while the other container is engaged in discharge–rechage operations. The inlet flow from the active container and pressurizing means to the n modules of the said battery is conducted to the modules via a line that is provided with extensions for each of the modules and the outlet flow of concentrate from the said modules is collected to the active container through other extensions connecting the modules a second line, leading to the container.

The scope of the invention is also intended to encompass the application of more than two containers per a single closed circuit of desalination, thus providing the means to conduct desalination sequences of shorter duration than

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the time required for the discharge and recharge operations of a single container.

Continuous desalination according to the inventive method using a battery with a plurality of modules(n) or using several batteries of this kind combined in parallel, is conducted in discrete desalination sequences of known recovery which are combined into a continuous process by means of the simultaneous exchange of spent feed container with fresh feed container by the procedure described in the context of Fig.2. The scope of the claimed inventive method covers apparatus with small batteries of limited number of modules designed for small scale desalination(e.g., the apparatus of Fig.2) up to a multitude of large batteries, each comprised of many modules, designed for large scale desalinaton operations.

Example I

The application of the new technology is exemplified in **TABLE-1** by sea water desalination under progressively increased pressure conditions using an apparatus of the schematic design shown in Fig.2 with 6 modules of parallel feed and a pair of containers of 600 liter each. The modules in this example are of a commercial type, or similar, with presumed minimum concentrate to permeate flow ratio of 5:1(r=5) and permeate flow(Q) of 24 m^3/day (16.67 liter/min). The presumed minimum ratio of applied counter pressure to osmotic pressure in this example of 1.35 ($p_{ap}=1.35p_{OP}$) at each concentration level, is the approximate ratio attained at modules outlet in CFD processes for single pass sea water desalination of 50% recovery. The presumed efficiency factors of pumps in this example are f_{PP}=0.88, f_{CP}=0.85 and f_R=0.80. The CP in this example is presumed to operate at an inlet-outlet pressure difference(Δp) of 1.0 Bar (15 psi), and the container discharge - recharge pump (DRP) is presumed to operate at a pressure(p) of 0.5 Bar(7.5 psi). The total maximum

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specific energy of desalination(SE*) under the conditions specified in **TABLE-1** is expressed by equation (8).

(8) $$SE^* (Kwh/m^3) = 0.03199\ p_{ap} + 0.1656 + 0.03518\ [V/v\}$$

The characteristic features of the sequential desalination example in **TABLE-1,** and of similar examples, include recovery(R_{ec}), duration of sequence(T), duration of container-full cycle passed though modules (T_{CFC}), number of container–full cycles per desalination sequence (N_{CFC}), and volume of permeate received per container-full cycle (v_{CFC}). The general terms **T, T_{CFC}, N_{CFC}, v_{CFC}** and **R_{ec}** are expressed by equations (9), (10), (11), (12) and (13), respectively, wherein **r** stands for concentrate to permeate flow ratio, **n** for the number of modules, each module having a permeate flow rate **Q, V** for container-full volume, and **v** for volume of released permeate. The volume of released permeate at time t (minute) from the start of sequence is expressed in the table by **n.Q.t** and this volume is equal to the volume of pressurized sea water supplied during the course of same time interval by the PP and monitored by the flow-meter(FM).

(9) $$T = \{1/(n.Q)\} \{(R_{ec}V)/(100-R_{ec})\}$$

(10) $$T_{CFC} = V/(r.n.Q)$$

(11) $$N_{CFC} = T/T_{CFC} = r\{R_{ec}/(100-R_{ec})\}$$

(12) $$v_{CFC} = T_{CFC}.n.Q = \{V/(r.n.Q)\}\{n.Q) = V/r$$

(13) $$R_{ec}=(100v)/(V+v)=100\{(N_{CFC}V)/r]/[V+(N_{CFC}.V)/r]\} = 100N_{CFC}/(r+N_{CFC})$$

The information disclosed in **TABLE-1** includes specific energy components as well as pressure (applied and osmotic) variations on the time scale of

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individual cyclic desalination sequences. The combining of several cyclic sequences into a continuous process is exemplified in this table by pressure variations of three consecutive sequences which typify a continuous process. Variations of osmotic pressure at inlet and outlet of modules as well as of applied counter pressure are expressed on a continuous time scale, or cumulative desalted volume scale, or cyclic sequence desalted volume scale. Applied counter pressure in modules is maintained at a fixed minimum ratio of 1.35 above osmotic pressure at modules outlet ($p_{ap}/p_{op} \geq 1.35$) or about 1.6 above osmotic pressure at modules inlet. The projected relationships of variable pressures and cumulative or cyclic sequence desalted volumes illustrate the pressure control mechanism by means of monitored (FM) volume.

The apparatus according to the specifications in **TABLE-1** for 137 m^3/day of desalted sea water on the basis of 95% availability and 50% recovery, requires mean specific energy of 1.911 Kwh/m^3 under variable counter pressure (39.7-67.3 Bar) or 2.35 Kwh/m^3 under constant counter pressure (67.3 Bar). The distinction between variable and constant counter pressure conditions in 3 consecutive cyclic sequences of this example is illustrated graphically in **TABLE-1** (**A** and **B**). The applied pressure control mechanism in cyclic sequences from monitored (FM) pressurized volume is illustrated graphically in **TABLE-1** (**C** and **D**) on a continuous or cyclic basis, respectively. The volume of desalted sea water(v), same as pressurized sea water, is proportional to recovery, thus indicating changes in concentrations and osmotic pressures during the sequential desalination process. In simple terms, the monitored volume range of 0-600 liter in the cyclic sequence of this example is concomittant with a linear counter pressure increase in the range of 39.7-67.3 Bar by the pressurizing pump.

The duration of cyclic sequences (T) of 6 minutes provides ample time for alternate container recharge even by means of gravity form an upper reservoir. The containers of 600 liter each used in this example can be viewed as

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pressure pipe sections of 25 cm radius and 306 cm length, and this to illustrate their simple construction by inexpensive means.

Apparatus of a design similar to that of the apparatus referred to in **TABLE-1** made to actuate at shorter cyclic sequences (T and N_{CFC}) enable the performing of continuous desalination with lower recovery and lower specific energy. The data disclosed in the table reveal mean specific energies of 1.911, 1.830, 1.753, 1.682 and 1.629 Kwh/m^3 for recoveries of 50.0, 45.5, 40.0, 33.3 and 27.9%, respectively. For instance, selection of a cyclic sequence duration of 3 minutes, instead of 6 minutes, for desalination in the apparatus under review implies a specific energy demand of 1.683 Kwh/m^3 in a continuos process of consecutive cyclic sequences with 33.3% recovery. Likewise, selection of a cyclic sequence duration of 2 minutes, instead of 6 minutes, for desalination in the apparatus under review implies specific energy demand of 1.629 Kwhm^3 in a continuous process of consecutive cyclic sequences with 27.9% recovery. The selection of cyclic sequence duration(T) for a given apparatus of fixed design affects the level of recovery and specific energy demand of the process without alteration of production rates.

The new technology described by the inventive method also applies to brackish water and this is exemplified in **TABLE-2** for a feed source of 0.70% concentration.

Example II

TABLE-2 is an example of brackish water desalination carried out with an apparatus of a design similar to that described for sea water desalination in **TABLE-1**. Brackish water desalination requires high recovery, since both feed source and effluent disposal constitute limiting factors for this process, especially if such process is carried out inland. The application of the novel technology of the invention to brackish water enables the attainment of high

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recovery by simple means of extensive recycling under progressively increased pressure conditions at considerable saving in energy. The desalination of brackish water (0.7%) with 89.3% recovery described in **TABLE-2** requires the mean specific energy of 1.217 Kwh/m^3 if the process is being carried out under variable pressure (7.9-57.5 Bar), and the mean specific energy of 2.01 Kwh/m^3 if the process is being carried out under contsant pressure (57.5 Bar) conditions. The extensive recycling of brackish water required for high recovery is manifested in TABLE-2 by the data of 41.7 container-full volumes required to be circulated through the desalination modules (N_{CFC}= 41.7) in order to attain the desired recovery level of 89.3%.

During the desalination of brackish water, the specific energy components, illustrated graphically in **TABLE-2** on the time scale coordinate, reveal major variations only with respect to the pressurizing pump(0.25 - 1.84 Kwh/m^3). The specific energy component of the circulating pump remains constant (0.17 Kwh/m^3) throughout the desalination sequence, whereas that due to container recharge corresponds to a minor contribution (0.042-0.004 Kwh/m^3) of decreased weight as function of increased recovery.

Applied counter pressure in modules during brackish water desalination is maintained at a fixed minimum ratio of $p_{ap}/p_{op} \geq 1.35$ above osmotic pressure at module outlet or about 1.6 above osmotic pressure at module inlet. The progressively increased counter pressure (7.9 – 57.5 Bar) during the course of the desalination sequence specified in **TABLE-2**, corresponds to a linear volume increase (0-5,000 liter) of monitored pressurized brackish water feed, the same as the volume of desalted water released. Therefore, the monitored volume of the pressurized brackish water provides the means to establish a variable pressure desalination sequence also in cases of extensive recycling required to attain high recovery.

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The embodiment of the invention is exemplifed in **TABLES 1** and **2** by the application of modules with characterisitics such as those offered commercially, and this in order to suggest the immediate availability of the new technology on the basis of existing components. The information disclosed in both tables includes the volume of containers (V, liter), number of modules(n), initial concentrations { C_{sw} or C_{BW} }, assumed ratio of osmotic-pressure(p_{OP}) to percent concentration [C(%)] of solution, and minimum ratio of applied counter pressure to osmotic pressure[p_{ap}/p_{OP}] of concentrate at module outlet. The Information in these tables which pertains to single element modules of the types offered commercially includes rated desalination flow(Q liter/min), minimum flow ratio of concentrate(Q') to permeate (Q) through module (r=Q'/Q), and feed flow percent (FFP) per module relative to an allowed maximum. The information pertaining to pressure includes the variable applied counter pressure(p_{ap}) supplied by the PP, the fixed pressure-difference of operation(Δp or delta-p) of the CP, and the fixed pressure of operation(p) of the RP. The information pertaining to efficiency-factor of components includes that of the pressurizing pump(f_{PP}), the circulation pump(f_{CP}), and the recharging pump (f_R). The selected factors in the tables are those of relatively high efficiency pumps. Other information common to both tables includes variables which affect the duration of the desalination sequence progress such as the volume of the fresly supplied pressurized feed (n.Q.t) and/or the volume of released permeate, the recovery (R_{EC}-%), the concentration in the container (C_c), the concentrations at modules inlet(C_i) and outlet(C_o) with their respective osmotic pressures (p_i and p_o), as well as the power and the specific energy requirements. at each stage during the process.

The examples in **TABLES 1-2** pertain to the same apparatus made to operate with different feeds at various conditions. Additional examples on the basis of the data disclosed in **TABLES 1-2** are specified in **TABLE-3**.

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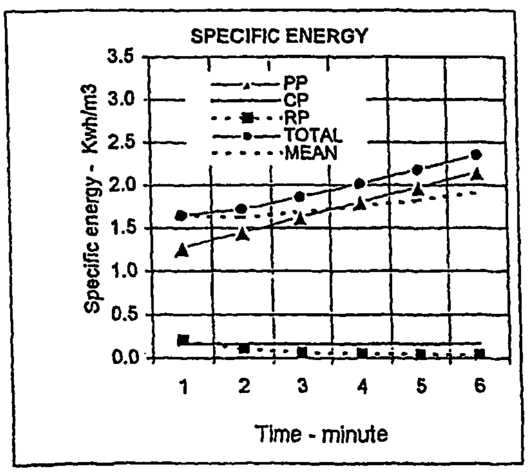
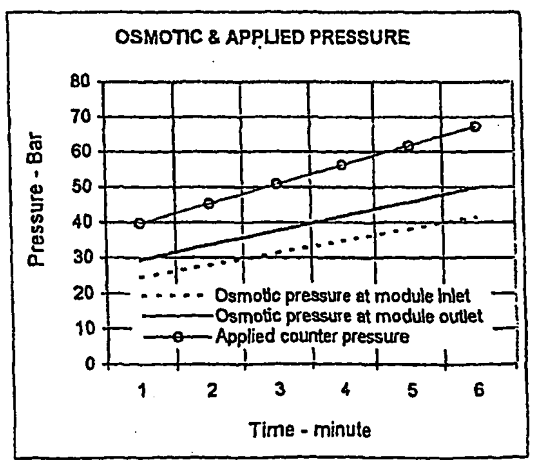
TABLE-1

Example-I of continuous desalination of sea water(3.5%) with 50% recovery by consecutive sequences, 6 minute each, using specified apparatus with 6 modules and 2 containers.

V	600 liter	Volume of container.
n	6 unit	Number of single element modules of specified charateristics.
V/n	100 liter	Container volume ratio per module
Q	16.7 lit/min	Rate of permeate flow per module (24 m^3/day).
Q'	83.3 lit/min	Circulation flow of concentrate at modules outlet.
r=Q'/Q	5.0 ratio	Minimum flow ratio of concentrate to permeate (miniimum ratio 5:1).
FFP	35.3 %	Feed Flow Percent relative to a presumed maximum of 17 m^3/h..
C_{SW}	3.50 %	Concentration of sea water feed.
$p_{op}/C(\%)$	7.00 ratio	Assumed ratio: [osmotic-pressure (Bar)] / [concentration(%)] .
p_{ap}/p_{op}	1.35 ratio	Assumed minimum ratio: [Applied-pressure] / [Osmotic-pressure] .
delta-p	1.0 Bar	Assumed inlet-outlet pressure-difference of circulating pump (CP).
p	0.5 Bar	Assumed pressure of discharge-recharge operation of container by pump(s).
f_{PP}	0.88 factor	Assumed efficiecny-factor of pressurizing pump(PP)
f_{CP}	0.85 factor	Assumed efficiecny-factor of circulating pump (CP).
f_R	0.80 factor	Assumed efficiency-factor of pump(s) for container discharge-recharge.
E_R	0.021 Kwh	Calculated energy of container discharge-recharge opereation.
R_{EC}	50.0 %	Calculated recovery of a complete desalination sequence..
T	6 min	Calculated duration of a complete desalination sequence.
T_{CFC}	1.20 min	Calculated duration of Container-Full Cycle circulation through modules..
N_{CFC}	5 number	Calculated number of Container-Full Cycles passed through modules..
DP	137 m^3/day	Daily production (DP) assuming availability of 95%.

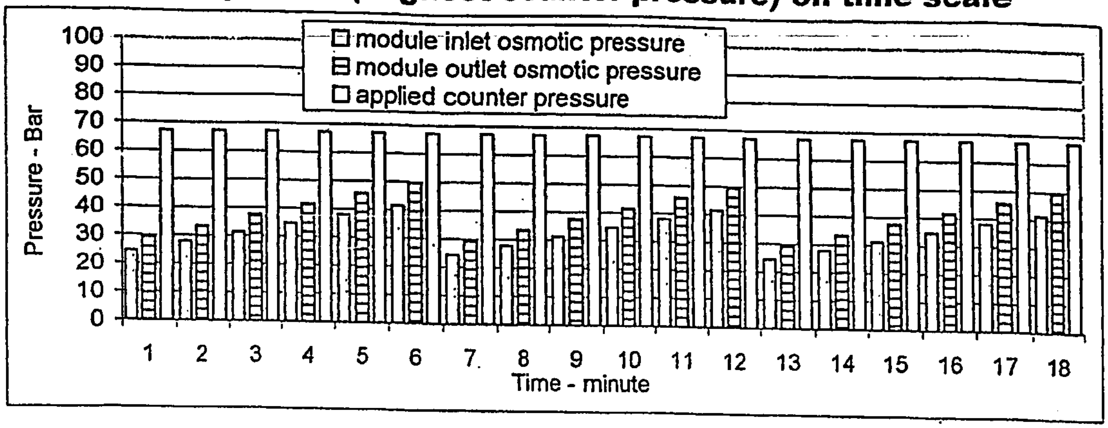
time		Desalt	Concentration(%)				Osmotic(Bar)		p_{ap}			Specific Energy				
t	CFC	n.Q.t	t-1	t-1	t	R_{EC}	t-1	t-1	t	Power(Kw)		Kwh/m^3 (permeate)				
min	N_{CFC}	liter	C_i	C_o	C_c	%	p_i	p_o	Bar	PP	CP	PP	CP	RP	total	mean
1	0.83	100	3.50	4.20	4.08	14.3	24.5	29.4	39.7	7.62	0.99	1.27	0.17	0.211	1.65	1.647
2	1.67	200	3.99	4.78	4.67	25.0	27.9	33.5	45.2	8.68	0.99	1.45	0.17	0.106	1.72	1.629
3	2.50	300	4.47	5.37	5.25	33.3	31.3	37.6	50.7	9.73	0.99	1.62	0.17	0.070	1.86	1.682
4	3.33	400	4.96	5.95	5.83	40.0	34.7	41.6	56.2	10.8	0.99	1.80	0.17	0.053	2.02	1.753
5	4.17	500	5.44	6.53	6.42	45.5	38.1	45.7	61.7	11.9	0.99	1.98	0.17	0.042	2.18	1.830
6	5.00	600	5.93	7.12	7.00	50.0	41.5	49.8	67.3	12.9	0.99	2.15	0.17	0.035	2.35	1.911



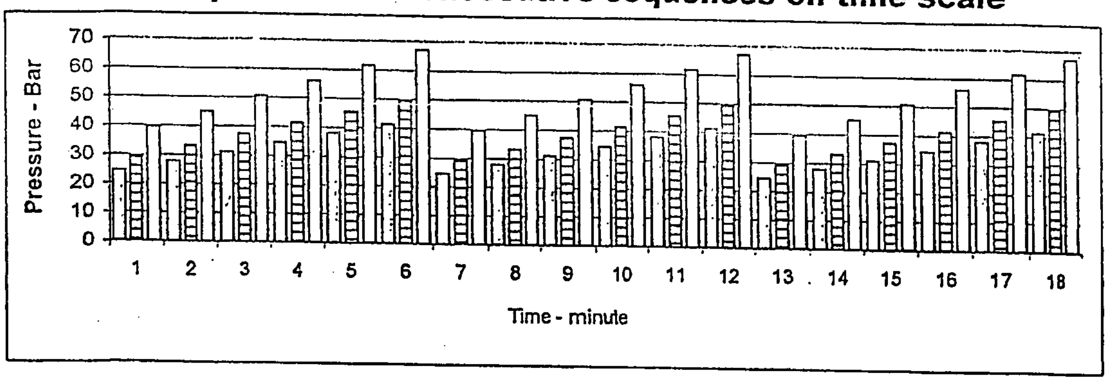


R_{EC}, percent recovery.	$C_c = \{(V+n.Q.t)/V\}C_{SW}$ - Container concentration at time t.
PP, pressurizing pump.	$C_i = (r\,C_c + C_{SA})/(r+1)$: Module inlet concentration at t-1 with osmotic prssure of p_i
p_{ap}, applied counter pressure.	$C_o = C_i\{(r+1)/r\}$: Module outlet concentration at t-1 with osmotic pressure p_o.
CP, circulation pump.	[Mean specific energy] = {PP(t=1)+PP(t))/2 + CP(t) + RP(t).
RP, recharge-discharge pump.	$T = \{1/(n.Q)\}\{(R_{EC}V)/(100-R_{EC})\}$ $T_{CFC} = V/(r.n.Q.)$ $N_{CFC} = T/T_{CFC}$

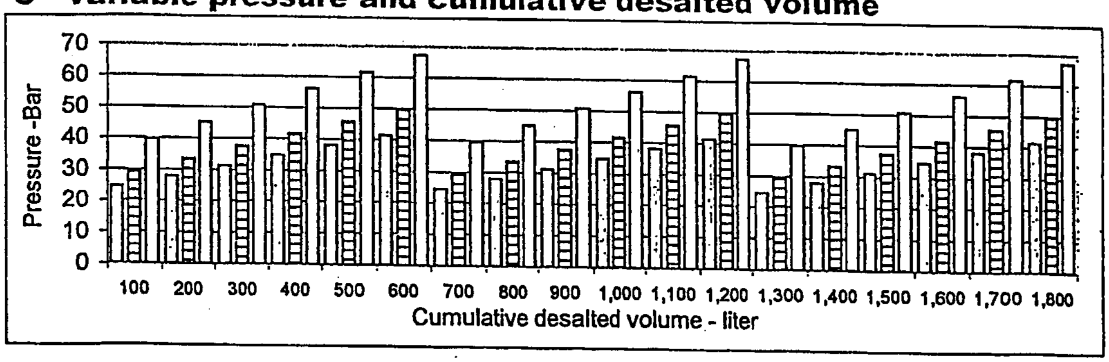
A - constant pessure(highest counter pressure) on time scale



B - variable pressure in consecutive sequences on time scale



C - variable pressure and cumulative desalted volume



D - variable pressure and sequential desalted volume

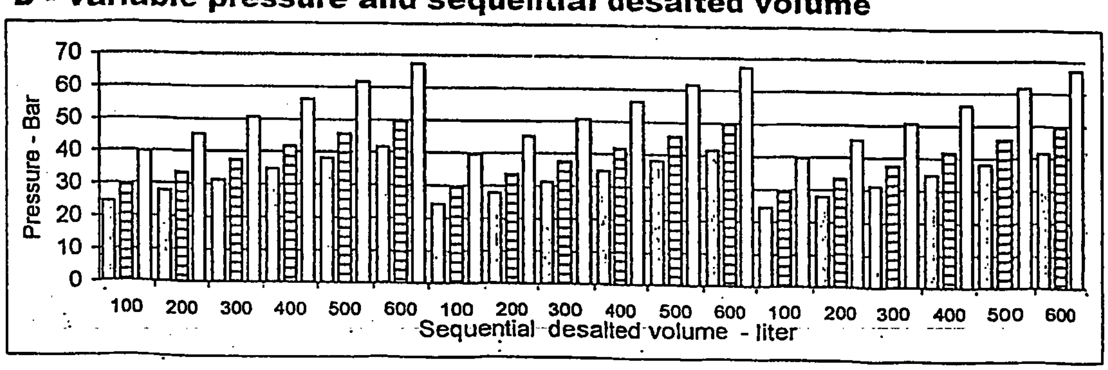


TABLE-3

TABLE-3 presents additional examples of sea water and brackish water desalination by the inventive method on the basis of the data disclosed in TABLES 1-2 for similar processes taking place under variable pressure and/or under constant pressure.

Feed water	Initial con(%)	Percent recovery	APPLIED Pressure(Bar) initial	final	Sequence duration(T) minute	CFC N_{CFC}	Mean Specific Energy Kwh/m^3	Reference
Sea	3.50	25.0	39.7	45.2	2.0	1.67	1.629	TABLE-1
Sea	3.50	25.0	45.2	45.2	2.0	1.67	1.720	TABLE-1
Sea	3.50	33.3	39.7	50.7	3.0	2.50	1.682	TABLE-1
Sea	3.50	33.3	50.7	50.7	3.0	2.50	1.860	TABLE-1
Sea	3.50	40.0	39.7	56.2	4.0	3.33	1.753	TABLE-1
Sea	3.50	40.0	56.2	56.2	4.0	3.33	2.020	TABLE-1
Sea	3.50	45.5	39.7	61.7	5.0	4.17	1.830	TABLE-1
Sea	3.50	45.5	61.7	61.7	5.0	4.17	2.180	TABLE-1
Sea	3.50	50.0	39.7	67.3	6.0	5.00	1.911	TABLE-1
Sea	3.50	50.0	67.3	67.3	6.0	5.00	2.350	TABLE-1
Brackish	0.70	62.5	7.90	14.4	10.0	8.3	0.529	TABLE-2
Brackish	0.70	76.9	7.90	24.5	20.0	16.7	0.695	TABLE-2
Brackish	0.70	83.3	7.90	35.5	30.0	25.0	0.867	TABLE-2
Brackish	0.70	87.0	7.90	47.5	40.0	33.3	1.042	TABLE-2
Brackish	0.70	89.3	7.90	57.5	50.0	41.7	1.217	TABLE-2

Monitoring Desalination Recovery

The inventive closed circuit desalination method is performed in sequences under either variable or constant pressure conditions and controlled according to data from means that indicate desalination recovery. By this method, a closed circuit desalination sequence is initiated at zero recovery and completed when the desired recovery has been attained. The systematic increase of recovery during a desalination sequence also provides the means for regulating the pressure delivery during a variable pressure desalination process. Instantaneous recovery at a given point of time during the desalination sequence reflects the concentration and the osmotic pressure of the recycled solution within the closed circuit. In the preferred embodiment the instantaneous recovery during a desalination sequence in progress is monitored by a flow meter means from the volume of pressurized salt water feed injected by the pressurizing pump into the closed circuit system, or from the volume of released permeate. Instantaneous recovery can also be monitored independently by the follow-up at real time of "in situ" concentrations in the said closed circuit, whereby concentration monitoring means may be applied in place of or together with the said flow meter means for the control of sequential desalination according to the inventive method.

Variable versus Constant Pressure Desalination

The variable counter pressure technology is always preferred for the continuous high recovery desalination of brackish water. Sea water desalination in the recovery range 27.9-40.0% (1.629 – 1.753 Kwh/m^3) appears favored in coastal regions, where neither sea water feed nor effluent disposal constitute limiting factors. The choice between constant and variable pressure modes at low sea water recovery resides on the balance of extra energy demand by the former versus the benefits gained by avoiding pressure control means required by the latter. Continuous desalination of sea water at high recovery is always favored energetically under variable pressure conditions in view of significant

saving in energy; for instance, 1.911 instead of 2.35 Kwh/m^3 for sea water recovery of 50%.

Feed filtration

The feed to apparatus of the new technology should not contain particulate matter which inhibits flow through modules and/or may damage the enclosed membrane elements. Particulate matter which moves freely without clogging, is not expected to accumulate in modules, especially since the content of containers is replaced frequently and effluent discharged. The new technology can be applied using single element modules of commercially available types, instead of the multi-elements modules required for CFD, wherein elements are joined "head-to-tail" to allow high recovery per single pass. The joining in line of modules and/or elements for CFD enhances the probability of clogging and requires fine filtration of the feed stock. Conversely, the parallel application of single element modules by the new technology reduces the probability of clogging, and implies less rigorous filtration of feed compared with the needs of CFD. Single elements modules designed for free passage of relatively large size particulate matter could eliminate completely the need for fine or ultra-fine filtration of the feed entered to apparatus of the new technology. Reference made in this invention to sea water and/or brackish water feed to apparatus of the new technology implies feed filtration to the level required to avoid the clogging of modules by suspended particulate matter.

Containers

No real attempts were made over the years to develop commercial desalination methods which utilize static pressurizing techniques, and this in light of prevailing views concerning the need for equipment of enormous size and volume for such processes. Attributions of "enormous size and volume" are obviously not true for the present invention which utilizes relatively small volume containers in a single closed circuit. Containers in the present invention can be viewed as pressure pipes of somewhat wider diameter connecting the closed

circuit between the circulation pump and the desalinization unit (**Fig. 2.**). Containers of 600 liter each exemplified in **TABLES 1-2** do not manifest "enormous size and volume", but instead, small sections of pipes which are part of the closed circuit in the apparatus.

The volume of the containers(**V**) in the present invention is derived from **n. Q, T** and R_{ec} according to (9) and/or from **r, n, Q** and T_{CFC} according (10) and/or from v_{CFC} and **r** according to (12), or from other, known relationships.

Flow outlet of containers in the apparatus (FIG.2) of the present invention should be in closed proximity to the inlet of the desalinization unit and this to allow fresh feed supply to reach modules quickly and with minimum mixing with effluent remaining in pipes after alternating the containers.

Continuous desalination by the inventive method is not limited to designs with two container means as depicted in Fig. 2 and the application of a larger number of containers in the design may be found advantageous for large scale desalination apparatus. In designs with more than two container means, at any point of time one of the said container means is connected to the desalination circuit while the remaining container means are disengaged from the circuit undergoing either discharge, recharge or pressurization. The application of more than two containers in a circuit design enables the attainment of short desalination sequences (T) using a large number (n) of modules while at the same time the total stored volume of all containers is kept at minimum.

Reference to the Method by Avero et al

The new technology involves recycling under variable counter pressure in a single closed circuit without the necessity to separate between solutions of different salinity and the attainment of continuity by means of consecutive sequences initiated by the alternating engagement of containers with fresh feed supply in the same circuit. By contrast, the method of Avero et al involves two

or more pairs of closed circuits each containing intricate means of separation between solutions of different salinity. The difference between the methods is manifested in apparatus construction which in case of the new technology involves exceptionally simple designs made of readily available commercial components, and this in sharp contrast with the inherent complexity of the apparatus described by Avero et al.

Advantages of the New Technology

Compared with continuous flow desalination(CFD) methods, the new technology provides the following advantages:

- Simple designs.
- Simple apparatus with readily available commercial components.
- Continuous processes comprised of consecutive sequences.
- Major savings in energy consumption (50% or more),
- Major savings in power components (50% or more),
- Major savings in construction costs.(50% or more).
- Saves on energy recovery means.
- Saves on pressure losses due to friction.
- Saves on infrastructure.
- Saves on maintenance and operational expenses.
- Environmental friendly, since saves energy and reduces fuel combustion.

While the invention has been described hereinabove in respect of particular embodiments, it will be obvious to those versed in the art that changes and modifications may be made without departing from this invention in its broader aspects and, therefore, the appended claims are to encompass within their scope all such changes and modifications as fall within the true spirit of the invention.

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CLAIMS

1. An apparatus for sequential closed circuit desalination of a salt water solution by reverse osmosis having at least one circuit that comprises: a container means; one or more desalination modules with their respective inlets and outlets connected to the said circuit in parallel; a line for conducting solution to be desalinated from the said container to the said desalination modules; a line for recycling desalinated solution from the said desalination modules to the said container; a circulation means for driving the recycling of the said solutions between the said container and the said modules; a pressurizing means for creating sufficient counter pressure to enable reverse osmosis desalination and replacement of released permeate by fresh salt water feed; means for effluent discharge and salt water recharge; means for monitoring the progress of desalination and control means that enable the said closed circuit desalinaton to be performed in sequences with either variable pressure, or constant pressure applied controllably during the said closed circuit desalination sequences such that the ratio of applied pressure to osmotic pressure at each stage during the said closed circuit desalination process is maintained above minimum predetermined value.

2. An apparatus for closed circuit desalination of a solution by reverse osmosis according to claim 1 that comprises a further container means and valve means for alternatingly connecting one or the other of the container means to the said circuit such that the container that is disconnected from the said circuit undergoes discharge and recharge while the container that is connected to the said circuit is actively engaged in the closed circuit desalination such that continuous

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operation of the modules throughout the said closed circuit desalination process is enabled.

3. An apparatus for closed circuit desalination of a salt water solution by reverse osmosis according to claim 1 that comprises more than two container means and a plurality of valve means for alternatingly connecting one or the other of the container means to the said desalination circuit wherein while one of the said containers is connected to the desalination circuit and actively engaged in the closed circuit desalination the remaining containers are disconnected from the said circuit and undergoing discharge of effluent and recharge of fresh salt water solution feed such that continuous operation of the desalination modules throughout the said closed circuit desalination process is enabled.

4. An apparatus for closed circuit desalination of a salt water solution by reverse osmosis according to any of the preceding claims wherein the said means for monitoring the progress of desalination is a means for monitoring the flow of fresh salt water feed into the said closed circuit.

5. An apparatus for closed circuit desalination of a salt water solution by reverse osmosis according to any of the preceding claims wherein the said means for monitoring the progress of desalination is a concentration monitoring means .

6. An apparatus for closed circuit desalination of a salt water solution by reverse osmosis according to any of the preceding claims wherein the said modules comprise semi-permeable membrane elements within a housing.

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7. An apparatus for closed circuit desalination of a salt water solution by reverse osmosis according to any of the preceding claims wherein the said modules are grouped in parallel batteries, each of the said parallel batteries comprising a plurality of modules.

8. An apparatus for closed circuit desalination of a salt water solution by reverse osmosis according to any of the preceding claims wherein the said container means are cylindrical conduit sections.

9. An apparatus for closed circuit desalination of a salt water solution by reverse osmosis according to any of the preceding claims wherein the said pressurizing means is a pressurizing pump, or more than one pressurizing pumps operated in parallel.

10. An apparatus for closed circuit desalination of a salt water solution by reverse osmosis according to any of the preceding claims wherein the said circulation means is a circulation pump, or more than one circulation pumps actuated in parallel or in line.

11. An apparatus according to any of the preceding claims for closed circuit desalination of a salt water solution by reverse osmosis wherein the said solution is sea water.

12. An apparatus according to any of the preceding claims for closed circuit desalination of a salt water solution by reverse osmosis wherein the said solution is brackish water.

13. A method for sequential closed circuit desalination of a salt water solution by reverse osmosis in a closed circuit with a container means, one or more desalination modules connected in parallel to the said circuit, line means for connecting between the said modules and the

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said container means, a pressurizing means, a circulating means, a means for monitoring the progress of the desalination process and a plurality of valve means, the said method consisting of desalination sequences, each sequence comprising the following steps:

a. filling the said closed circuit with fresh salt water solution under atmospheric pressure

b. sealing the said closed circuit and pressurizing the said fresh salt water solution within the said closed circuit

c. recycling the pressurized salt water solution through the said desalination modules at a predefined flow rate by means of the circulation means such that permeate is released efficiently from the said modules

d. controlling the duration of the desalination sequence and the pressure applied during the said desalination sequence according to the progress of desalination recovery as indicated by a monitoring means

e. collecting the desalinated solution from the said modules;

f. stopping the desalination sequence at a predetermined desalination recovery value and disconnecting the said container means from the said closed circuit

g. releasing the pressure in the said container means by opening the said container means to atmospheric pressure

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h. discharging the concentrated fluid from the said container means under atmospheric pressure

i. repeating the process from step a.

14. A method for closed circuit desalination of a solution by reverse osmosis according to claim 13 hereinabove in a closed circuit that comprises a first container means and a second container means wherein the said first container means may be disengaged from the said circuit to be discharged, recharged and pressurized while the said second container means is connected to the said circuit, such that the desalination sequence may be operated continuously by alternating between the said first and second container means

15. A method for sequential closed circuit desalination of a salt water solution by reverse osmosis according to claim 13 hereinabove in a closed circuit comprising several container means, wherein while one of the said containers is connected to the desalination circuit and actively engaged in the closed circuit desalination the remaining containers are disconnected from the said circuit and undergoing discharge of effluent, recharge of fresh salt water solution feed and pressurization such that continuous operation of the desalination modules, the pressurizing means and the circulating means throughout the said closed circuit desalination process is enabled.

16. A method for sequential closed circuit desalination of a salt water solution solution by reverse osmosis according to any of claims 13-15 hereinabove wherein the applied pressure output of the said pressurizing means is gradually increased during the desalination sequence as a function of the increase of desalination recovery monitored by the said monitoring means, such that the ratio of applied

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pressure to osmotic pressure is maintained above a predetermined minimum value throughout the desalination sequence.

17. A method for sequential closed circuit desalination of a salt water solution by reverse osmosis according to any of claims 13-15 hereinabove wherein constant counter pressure is applied throughout the desalination sequence such that the said constant counter pressure is maintained at a predetermined minimum ratio above the osmotic pressure of the effluent solution discharged at the end of each desalination sequence.

18. A method for sequential closed circuit desalination of a salt water solution by reverse osmosis according to any of claims 13-17 hereinabove wherein the said monitoring means is a flow meter means that monitors the volume of fresh salt water feed into the system.

19. A method for sequential closed circuit desalination of a salt water solution by reverse osmosis according to any of claims 13-17 hereinabove wherein the said monitoring means is a concentration monitoring means.

20. An apparatus for closed circuit desalination substantially as described herein with reference to the drawings.

21. A method for closed circuit desalination substantially as described herein with reference to the drawings.

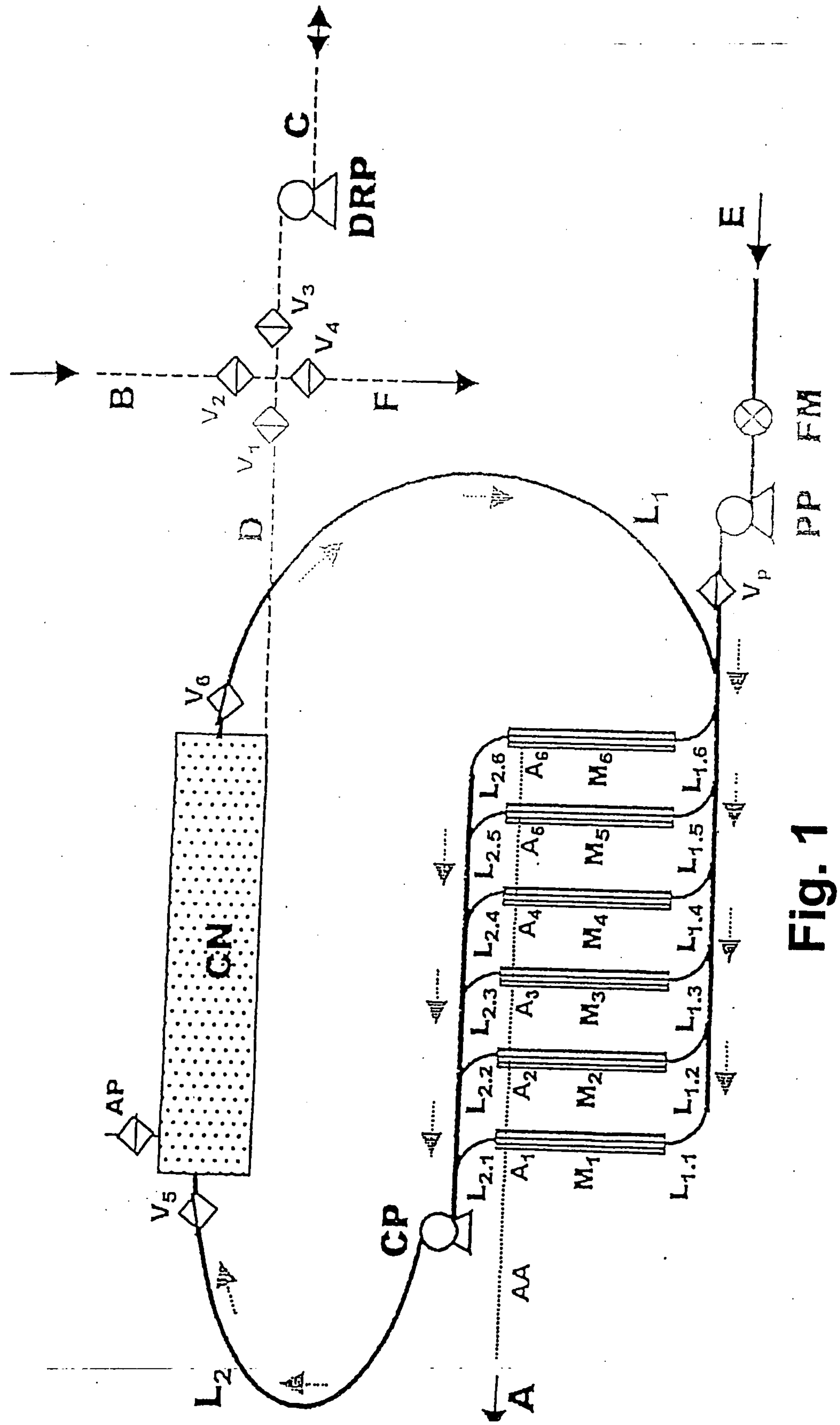
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Fig. 1

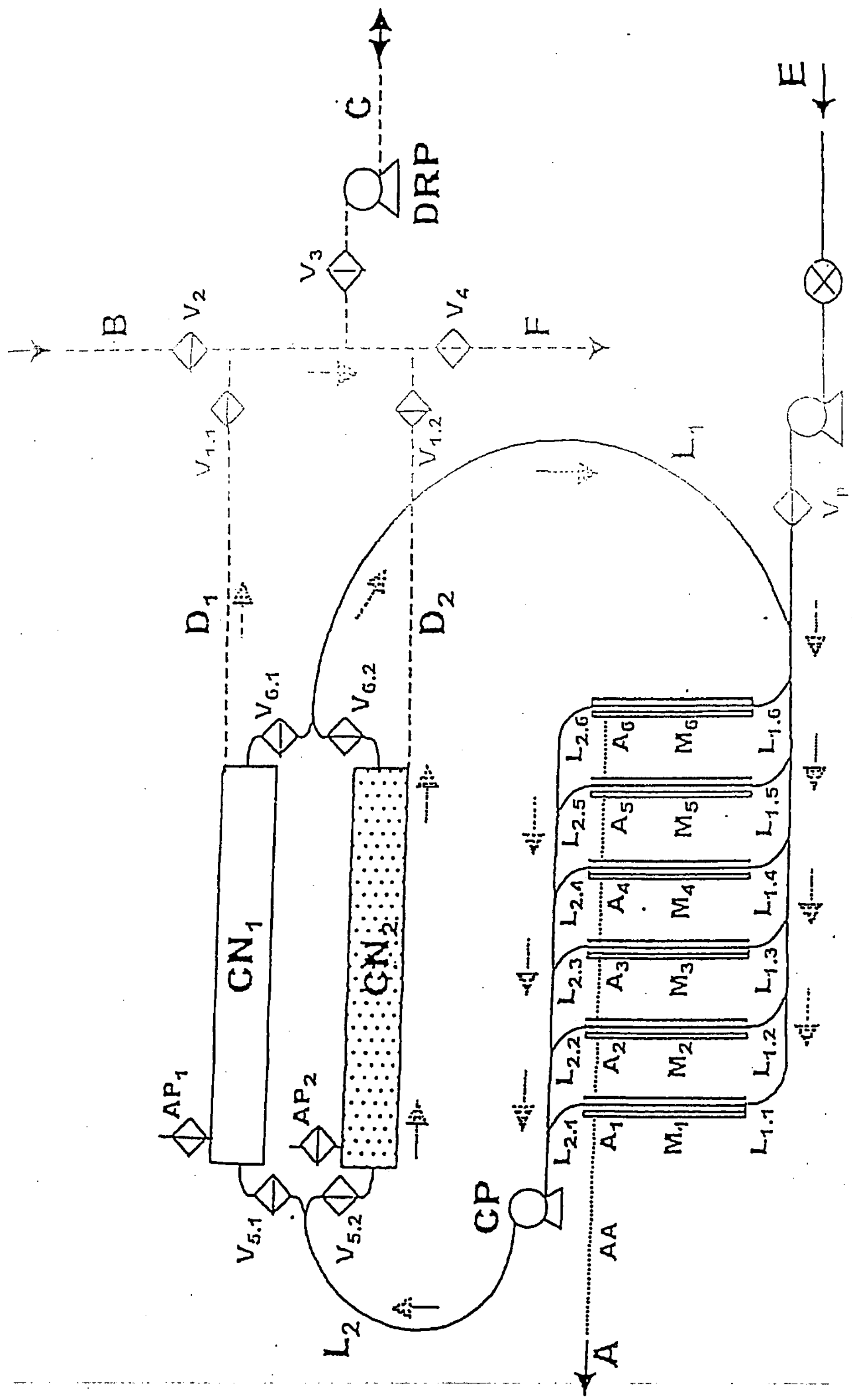
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Fig. 2

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